A NEW BLENDED ANALYSIS OF SNOW DEPTH

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OUTLINE

- Motivation
- Optimum Interpolation of Snow Depth
- Snow Depth Analysis Description
- Application Examples
- Off-Line Validation
- Conclusions

Motivation

❖Accurate initialization of land states including **snowpack** is critical in **Numerical Weather and Climate Prediction systems** because of their regulation of simulated water and energy fluxes between the land surface and atmosphere over a variety of time scales.

❖ In-situ Snow Depth (SD) is only locally representative/accurate and unevenly distributed , whereas satellite remotely sensed SDs have much improved spatial coverage but with a lower absolute accuracy

❖**Larger Context/Hypothesis: Can a globally applicable SD estimation scheme be developed that blends multi-source data consistently?**

❖ **Can Analyst SD updates within the Interactive Multi-Sensor Snow and Ice Mapping System (IMS) be also blended into such a scheme?**

Interactive Multi-Sensor Snow and Ice Mapping System (IMS)

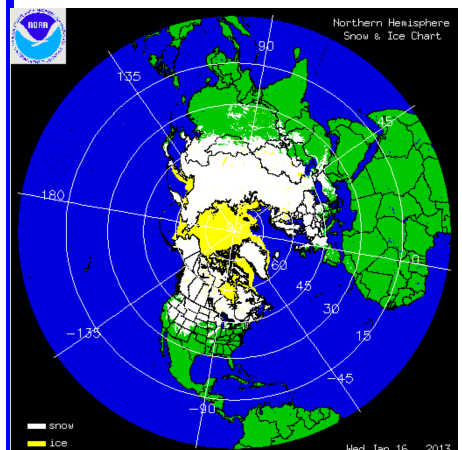
Version 2: Key Features:

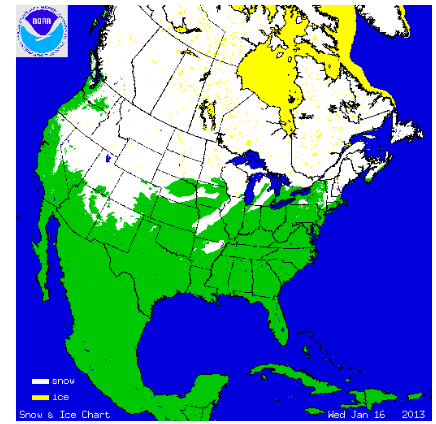
- 4 & 24km Northern Hemisphere
- Applied by NCEP for NWP models and for climate monitoring
- Other modeling agencies (FNMOC, ECMWF, UKMET) also apply it for snow initialization
- 1Xday production
- Interactive Multi-source : A large array of sat, radar, surface, webcam & model data and products available for the analyst

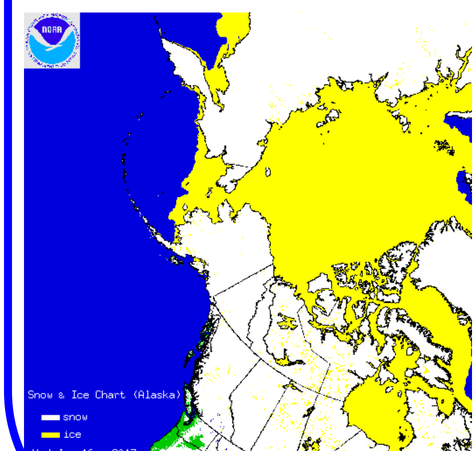
Version 3: New Capabilities in 2014:

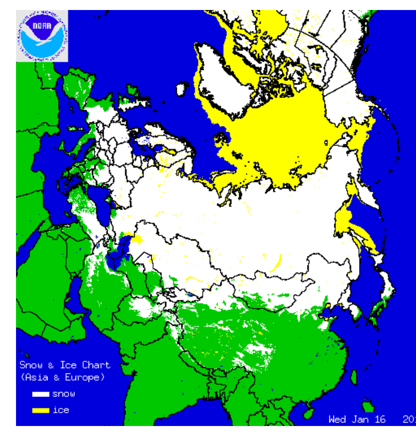
- 1-km resolution of SCA
- 2-km Automated Snow and Ice Analysis over the Southern Hemisphere
- 2Xday production
- A 4-km Snow Depth Analysis over the Northern hemisphere
- Ingest of additional data sources

Output Examples:









Global SD ANALYSIS FOR NWP - Canadian Meteorological Center (CMC) Brasnett 1999 J. Applied. Meteorol.

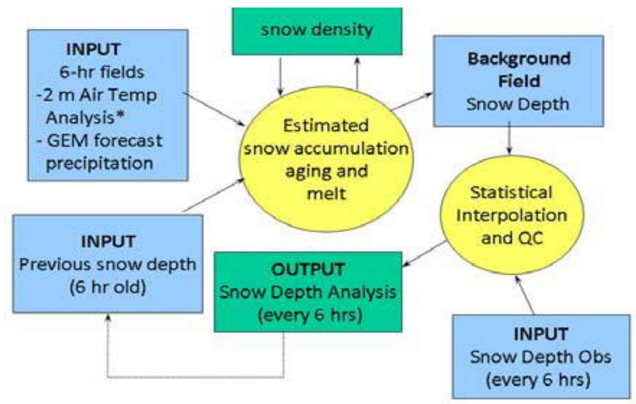
KEY FEATURES

❖ <u>2-D Optimal Interpolation </u>(OI) since March 1998, at 24-km & every 6 hours

❖ <u>Initial guess </u>- a simple snow accumulation and melt model using analyzed temperatures and forecast (six hour) precipitation from the CMC Global Environmental Multiscale (GEM) forecast

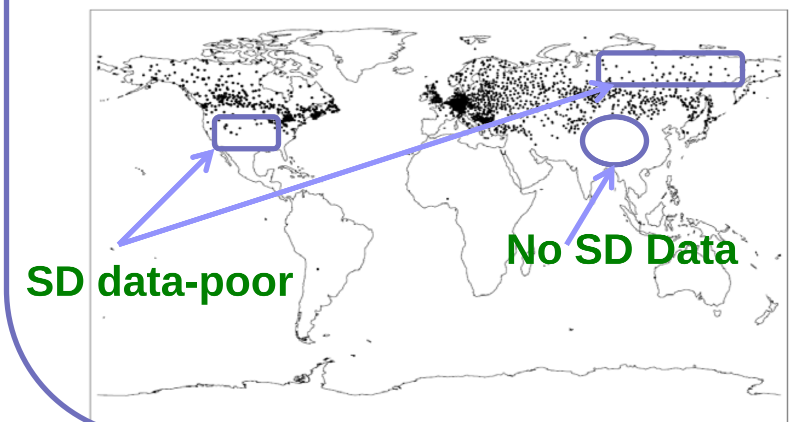
❖ <u>Driven by in-situ SD observations</u>; In regions where there are no SD observations, **analysis SD corresponds to the initial guess field.**

Operational CMC SD Analysis Flowchart

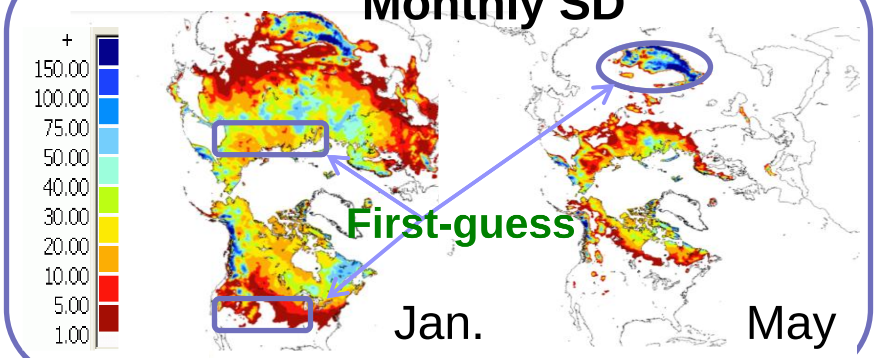


* Air temp corrected for difference in elevation between GEM model grid and snow depth analysis grid

SYNOP STATIONS



Monthly SD



Optimum Interpolation (OI) as a Multi-Source SD Estimation Method

- **SD** increment *at analysis point k* $\Delta \boldsymbol{SD_k}$ is computed as the weighted average of observed increments $\Delta \boldsymbol{SD_i}$ surrounding *k*:

$$\Delta SD_k = \sum_{i=1}^{N} w_i \Delta SD_i$$

*ΔSD_i is the difference between the **observed SD** and the **first guess SD** at each observation point i [i = 1, N]*

- The vector of optimum weights at ***k*** is given by solving the set of N linear equations of the matrix form:

$$\underline{w} = (\underline{B} + \underline{O})^{-1} \underline{b}$$

$\underline{B}$ *is correlation coefficient matrix of background errors between all pairs of observations*

$\underline{b}$ *is the vector of correlation coefficients of background errors between pairs of of observations and analysis point k*

$\underline{O}$ *is the covariance matrix of observational errors (normalized by the background error variance) between all pairs of observations*

SD OI Method (Con't)

- Correlation coefficients for each term in $\underline{B}$ and $\underline{b}$ are computed following ***Brasnett 1999. J of Applied Meteorol.***:

$$\mu_{ij} = \alpha(r_{ij})\beta(\Delta z_{ij})$$

μ_{ij} *is the correlation coefficient between each pair of observations or between each observation and analysis point,* r_{ij} *is the horizontal distance between pairs and* Δz_{ij} *elevation difference between pairs:*

2nd order autoregressive correlation function for distance

$\alpha(r_{ij}) = (1 + cr_{ij}) \exp(- cr_{ij})$ $c = 0.018\ km^{-1}$ *(horizontal scale ≈ 120 km)*

Square exponential correlation function for elevation

$\beta(\Delta z_{ij}) = \exp(- (\Delta z_{ij}/h)^2)$ $h = 800\ m$ *(vertical scale = 800 m)*

$\underline{O}$ **=** $(\sigma^2_{o}/\sigma^2_{b}) \times I$ *where I is the identity matrix and* $(\sigma^2_{o}/\sigma^2_{b})$ is the observation error variance normalized by the background error variance

NOAA's NEW OPERATIONAL SD ANALYSIS SCHEME

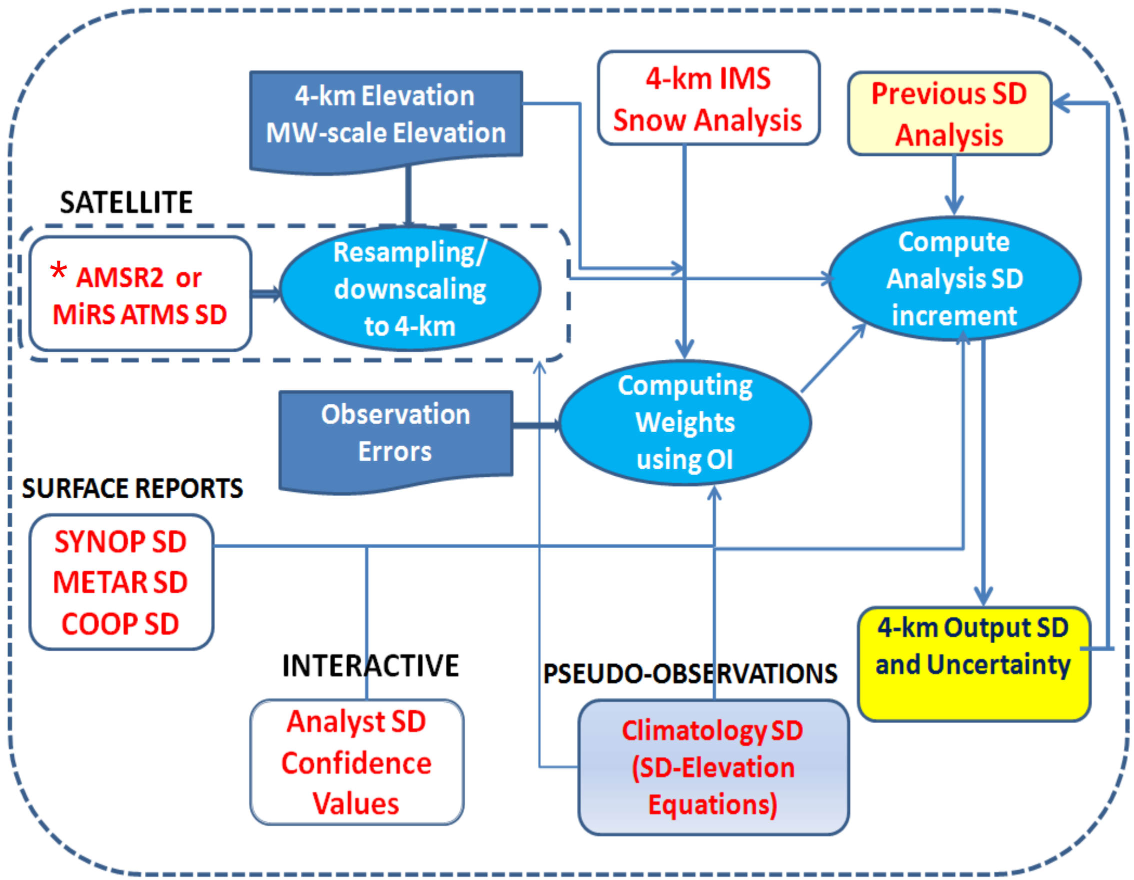
Key features:

❖ 2-D OI Analysis integrated into IMS V3

❖ Multi-Source Scheme: MW+in-situ + Climatology + Analyst Updates

❖IMS Analyst SD and Uncertainty estimates are also ingested into OI as independent data stream

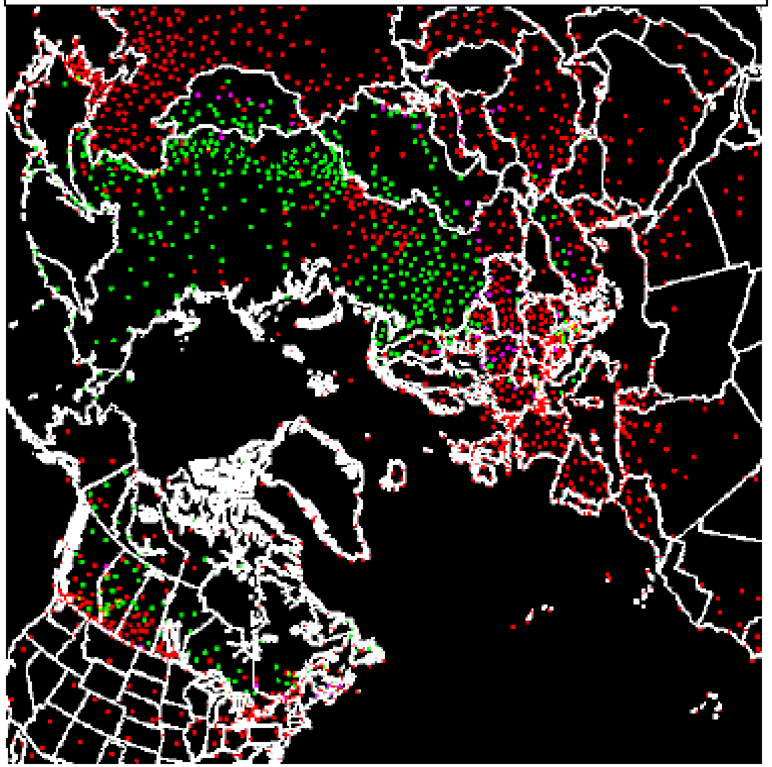
❖ MW Downscaling based on elevation



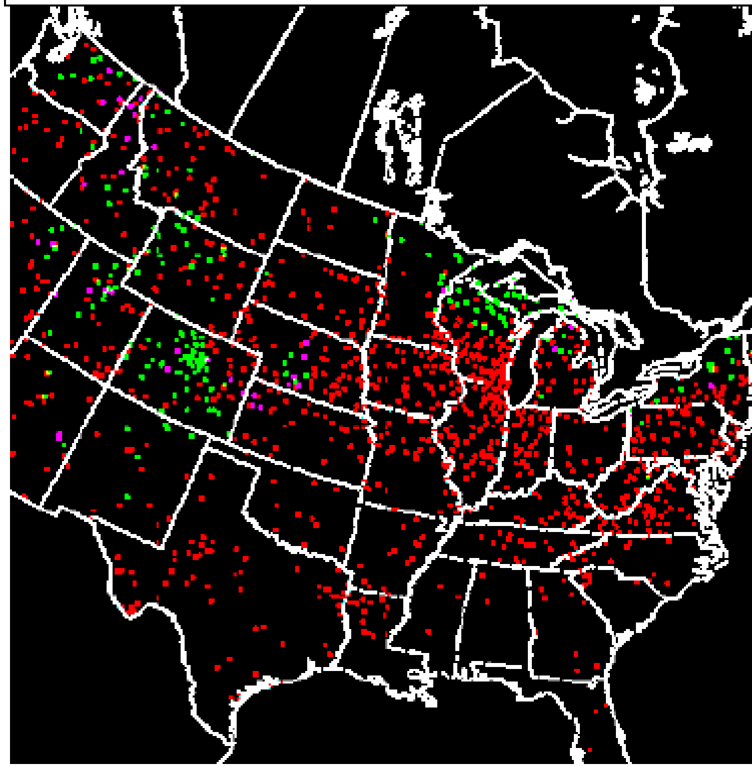
** NOAA's Global Change Observation Mission (GCOM) AMSR2 SD is first option and expected to go operational this year*

SURFACE SD REPORTS

SYNOP Station Reports Display in IMS V3



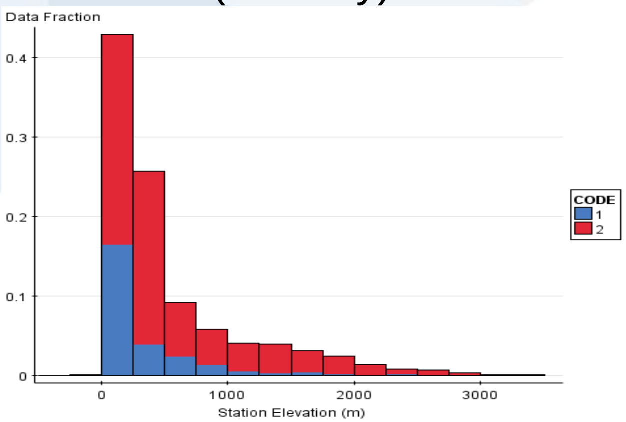
COOP Station Reports Display in IMS V3

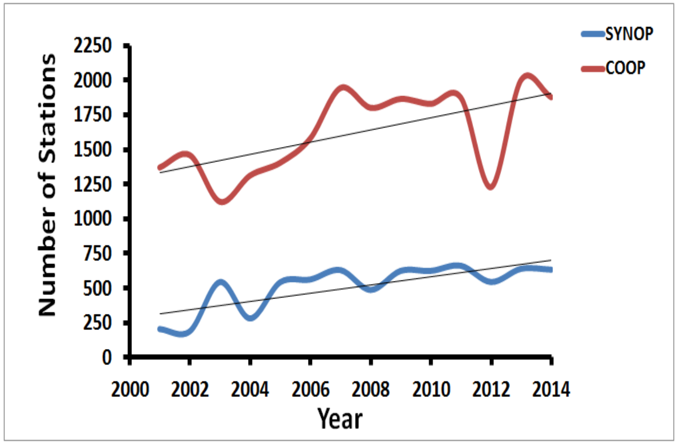


- = Surface report with SD = 0 and SF = 0
- = Surface report with SD = 0 but SF > 0
- = Surface report with SD > 0

CLIMO-BASED SD-ELEVATION RELATIONSHIPS

Elevation and annual distribution of non-zero SYNOP (Blue) and COOP (red) stations (January)





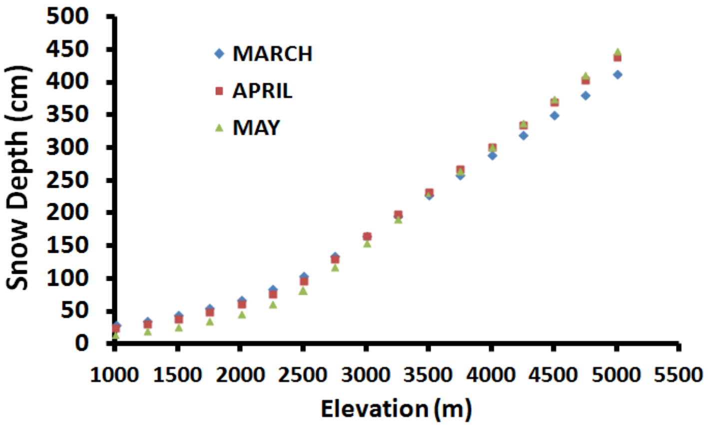
For Elev < 2500 m

SD = *a1* * exp(*b1Elev)**

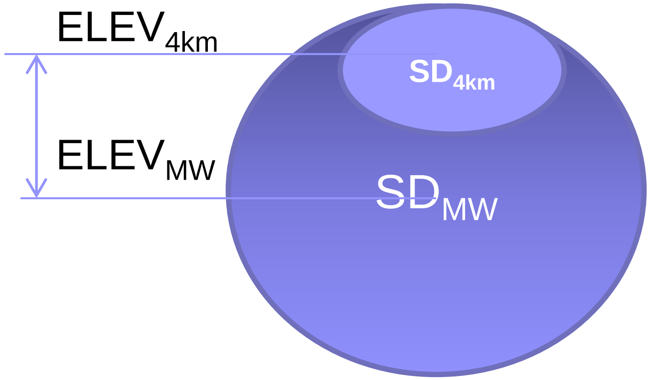
For Elev >= 2500 m

SD = a2 + b2*SD

Where a1, b1, a2,b2 monthly coefficients



MW-Downscaling based on Elevation



$$SD_{4km} = SD_{MW} + \Delta SD_{4km}$$

$$\Delta SD_{4km} = \boxed{\left(\frac{\Delta SD}{\Delta ELEV}\right)}(ELEV_{4km} - ELEV_{MW})$$

For SD < 2500 m: SD = *a1* * exp(*b1ELEV)**

ΔSD/ΔELEV = a1*b1*exp(b*ELEV)

For SD > 2500 m: SD = *a2* + b2*ELEV

ΔSD/ΔELEV = b2

ANALYST- GENERATED SD DATA

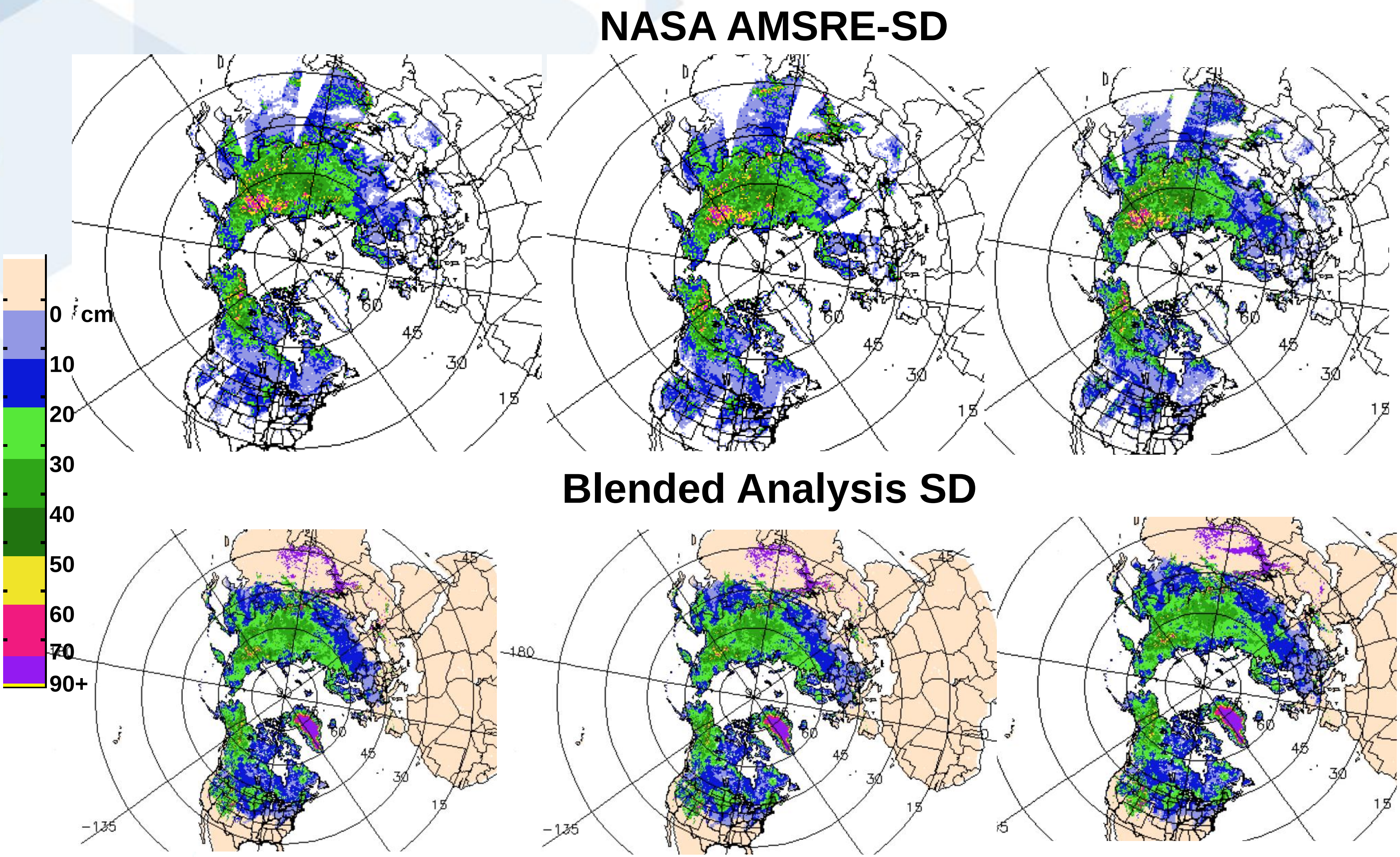
❖ In addition to automated data, IMS Analyst interactively generates (geo-referenced) SD data and confidence values, the latter on a scale of 1:9, which are treated as independent observational data input to OI analysis.

❖ The IMS Analyst confidence values are mapped to OI error values as a linear combination of smallest (in-situ) and largest (climatology) observational errors.

EXAMPLE APPLICATIONS OF AUTOMATED ANALYSIS

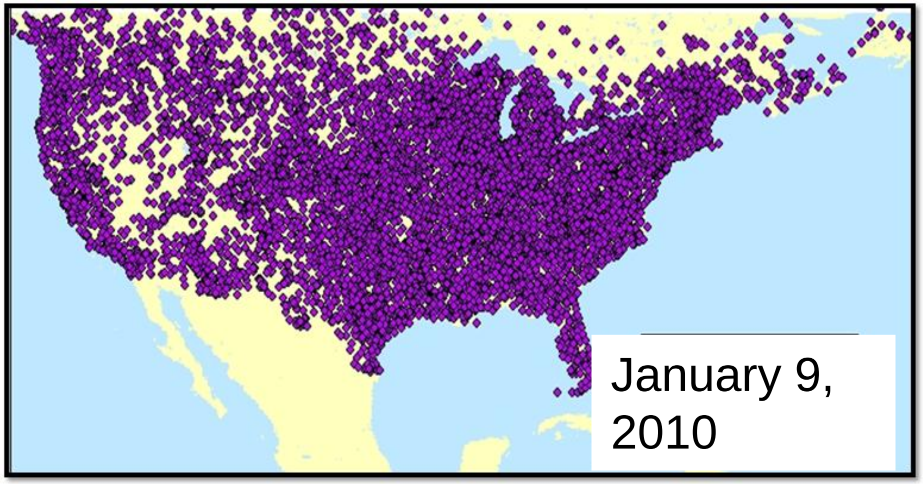
- **IN_SITU DATA:**
  SYNOP + METAR from McIDAS AND COOP from NCEP
- **MW DATA:** NASA AMSRE SWE (AS AMSR2 PROXY converted to SD
- **OBSERVATIONAL ERRORS:**
  0.5 for in-situ
  1.0 for MW
  1.5 for climatology
- **FIRST GUESS:** previous-day analysis

AMSR-E SD Versus Blended SD January 2- 4, 2010



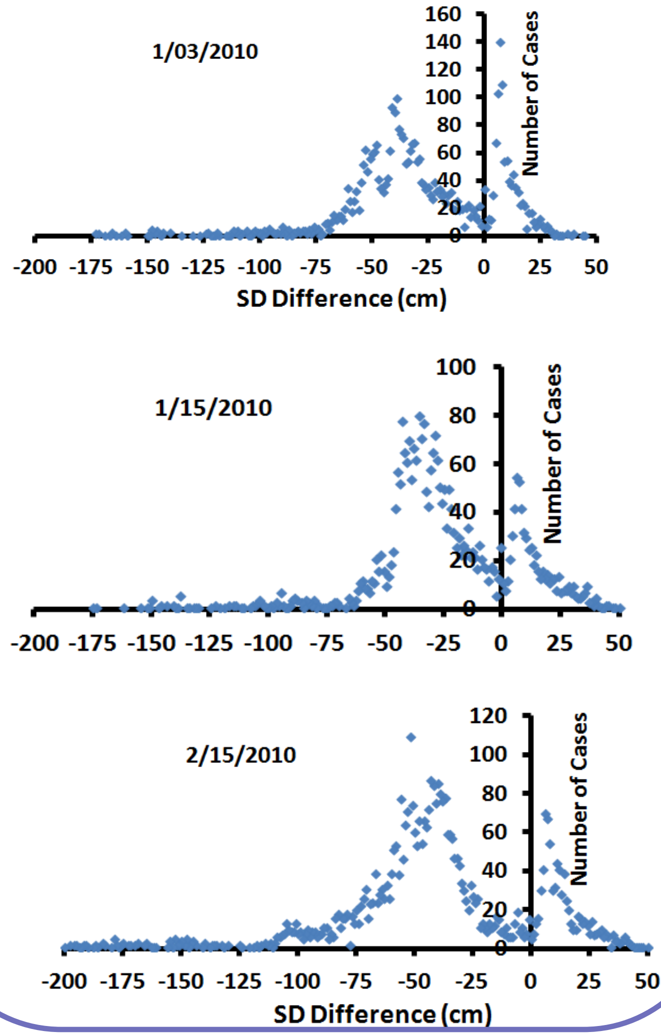
OFF-LINE VALIDATION - APPROACH

❖ Jan-February 2010 using AMSRE SD as MW Proxy and independent in-situ ground truth data from the Global Historical Climatology Network (GHCN) daily
❖About 10,000 snow-depth stations including SNow TELemetry (SNOTEL) & **Co**mmunity **Co**llaborative **Ra**in, **H**ail and **S**now Network (CoCoRaHS)
❖ Unlike COOP and SYNOP, validation data included a wide SD & Elevation Variability
❖ Zero snow depth excluded from analysis as well as COOP and SYNOP inputs to SD Analysis



OFF-LINE VALIDATION - RESULTS

- In Jan 2010, SD Analysis within 20 cm of the GHCN-Daily measurements 86.9% in snow covered areas, while in Feb 2010 within 20 cm 85.1% of the time. This is a very good overall result considering large SD variability, 4-km res. and inclusion of high elevation areas
- *Bi-modal distribution of errors – low bias/RMSE in low-elevation areas (4/7cm) and larger bias/RMSE in high elevation areas (35 cm/45 cm)*
- *RMSE still reasonable over high elevation terrain considering large SD values*



CONCLUSIONS

- ***A new optimal analysis of snow depth has been implemented at NOAA that blends multi-source data - microwave, in-situ and analyst estimates - consistently. Evaluation of the automated algorithm with in-situ and AMSRE snow depth data showed overall good results.***

- ***Ingest GCOM-W1 AMSR2 snow depth data into the analysis.***

- ***Microwave snow depth data need to be bias-corrected a. since optimal analysis method assumes no biased data, and b. to improve analysis over high elevation and data-poor areas.***

- ***SYNOP and COOP snow depth data are heavily skewed toward low-elevation areas. Ingest additional in-situ data sources e.g., GHCN Daily to improve analysis.***

- ***SD-Elevation relationships used in the analysis need to be improved using regional snow climate data.***